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SIRTF — The Next Step

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SIRTF — THE NEXT STEP*

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SUMMARY

This paper describes the scientific and technical background and prospects for the Space Infrared Telescope Facility, SIRTF. SIRTF is a superfluid-helium-cooled, 0.85-meter infrared telescope to be placed in orbit in 1993. It will carry out photometry over the wavelength range 2 to 700 μm, and diffraction-limited imagery in either broad or narrow spectral bands over the range 1.8 to 200 μm, down to flux levels of 10^{-6} janskys at 2 μm, about 10^{-4} janskys in the range 15 to 200 μm and 10^{-2} janskys at 700 μm. These fluxes are up to 10^{4} times fainter than currently achievable levels. SIRTF will measure spectra in the range 2.5 to 200 μm with resolving power between 50 and 1000. The focal plane will contain about 20,000 detector elements, both discrete and in arrays, which will operate at sensitivity levels set by the astrophysical background. SIRTF will be a long-lived (≧10 yr) facility providing opportunities for general investigations by the entire scientific community.

SIRTF will be ideal for following up the all-sky survey carried out by the Infrared Astronomical Satellite (IRAS). SIRTF can do a deep survey to flux levels 5000 times fainter than IRAS and obtain spectra of even the faintest IRAS sources. SIRTF will provide powerful capabilities for the study of astrophysical problems ranging from the formation of planetary systems and the nature of the Sun's nearest neighbors to the formation of galaxies in the early universe.

INTRODUCTION

A recent headline in the New York Times was, "The Golden Age of Astronomy Peers to the Edge of the Universe." Underneath were artists' conceptions of four space facilities that are major components of this golden age--the Gamma Ray Observatory (GRO), the Hubble Space Telescope (ST), the Advanced X-Ray Astronomy Facility (AXAF), and the Space Infrared Telescope Facility (SIRTF). This paper describes the fourth of these facilities, SIRTF. SIRTF is a 1-meter-class, long-duration, superfluid-helium-cooled telescope in Earth orbit, equipped with imaging and

*This paper is based on presentations by F. Gilbert at the 164th Meeting of the American Astronomical Society, June 1984, and by M. Werner at the Kuiper Airborne Observatory 10th Anniversary Symposium, July 1984.

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spectroscopic instrumentation operating over the wavelength range 1.8 to 700 μm. We will show that SIRTF is the next step scientifically; it will be by far the most powerful tool available for studying many of the most compelling problems in contemporary astrophysics and for further exploring the richness and variety of the infrared sky demonstrated by the Infrared Astronomical Satellite (IRAS). Second, we will show that SIRTF is the next step technically; this enormous gain in scientific capability does not imply a similar jump in technological capability, but builds on our current capabilities and flight-demonstrated critical technologies. The SIRTF studies have progressed to the point of readiness for the detailed definition and design of the facility and instruments.

SETTING THE STAGE FOR SIRTF

Over the past 20 years, as infrared astronomy has grown and matured, many of the techniques used in the infrared--telescopes, spectrometers, photometers, filters, and observing techniques--have been adapted from optical astronomy. There are, however, two areas of technological development unique to the infrared. The first is detection devices. The development and evolution of detectors for infrared astronomy have advanced to the point that, for most applications in the 3- to 200-μm range, detector noise no longer limits instrument performance. In addition, the last few years have seen the beginning of a revolution in infrared astronomy with the initial availability of self-scanned arrays. This development is very important to SIRTF and will be discussed in more depth later.

The second area of development unique to the infrared is that of cryogenically cooled space telescopes. Thermal emission by an ambient-temperature telescope and by the atmosphere, and atmospheric absorption, greatly limit the range and sensitivity of observations at infrared wavelengths beyond 2 μm from ground-based, airborne, or balloon-borne telescopes. Observations from above the atmosphere open up the entire infrared wavelength range, and cooling the telescope to cryogenic temperatures allows observations at a sensitivity level limited only by the natural astrophysical background. In the 1- to 100-μm range, this background is due to scattered sunlight and thermal emission from the zodiacal dust particles. Beyond about 100 μm, emission from interstellar dust grains and the 2.7 K cosmic background are expected to be dominant. Over the critical 5- to 200-μm wavelength range, the natural background is about 10^7 times lower than the atmospheric and telescope background emission typical of previous infrared measurements (fig. 1). Since the limiting noise varies as the square root of the background, a cryogenic space telescope can bring a gain of more than a thousand in sensitivity for infrared observations.

The first major space facility to exploit this gain was IRAS. IRAS, a joint project of the United States, the United Kingdom, and the Netherlands, carried out an all-sky survey in four broad wavelength bands between 8 and 120 μm. The success of this project is very important to SIRTF both scientifically and technically. Scientifically, IRAS showed the richness and variety of the sources available for

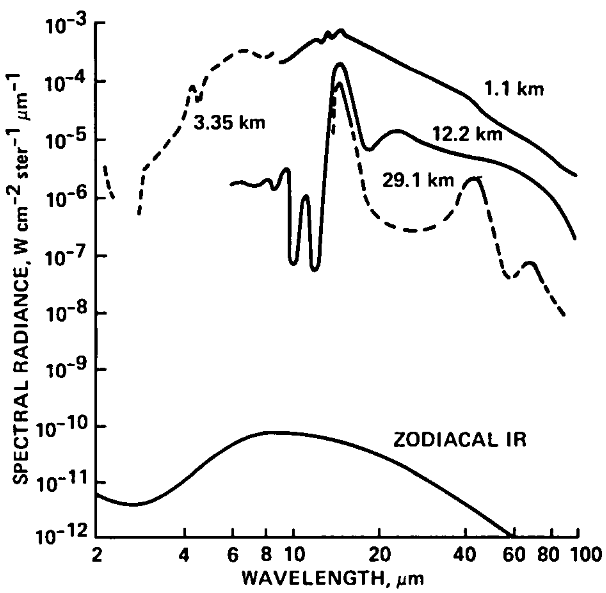

Figure 1.- The natural astrophysical background (lower curve) in the infrared is compared with the background caused by atmospheric emission as seen by ground-based and suborbital telescopes at various altitudes.

study by a cryogenically cooled space telescope. The IRAS catalogs will provide the fundamental information about the sky that is crucial to the best use of SIRTF. The IRAS survey detected about 250,000 sources, including new comets and dust bands in the solar system; unsuspected material around main sequence stars; complex clouds of interstellar dust; and very red, extremely luminous extragalactic sources. Technically, IRAS was also a critically important precursor to SIRTF. IRAS was the first large super-fluid helium dewar in Earth orbit. It demonstrated containment of superfluid helium in zero g and also addressed such questions as the effects of helium sloshing on pointing, the degradation of optical surfaces and solid state detectors over long periods of orbital operation, and the susceptibility of a cryogenic telescope to contamination by the residual atmosphere, dust particles, or other processes. All of these areas were major concerns prior to IRAS, and all were found to be insignificant during the mission.

The success of IRAS has already had a significant impact on SIRTF. Astronomers have long realized that a cryogenically cooled telescope in Earth orbit would be an extremely powerful scientific tool, and a series of peer review reports, most recently the 1982 Astronomy Survey Committee report of the National Academy of Sciences, have recommended continued active development of SIRTF. The initial SIRTF concept utilized the Space Shuttle as an initial observing platform with frequent reflights, possible instrument changes, and eventual conversion to a long-duration free flyer. The scientific and technical success of IRAS, together with the recent rapid evolution in detector technology and new information on the projected frequency and duration of Shuttle flights, have now made it overwhelmingly evident that the Shuttle-attached phase is neither desirable nor necessary. As a result, a

decision to proceed directly with the long-duration SIRTF was made by NASA in May 1984.

In the following sections, we will discuss the scientific implications of this long-duration SIRTF. The specific concepts presented are based on the Phase A SIRTF study recently completed by the Ames Research Center. This will very probably not be the final form of SIRTF, since it has not been subject to final review by the SIRTF Science Working Group or to a detailed design study, but the broad outline should be representative.

THE CAPABILITIES OF SIRTF

Figure 2 shows a cutaway view of SIRTF without its spacecraft. The Cassegrain optical system surrounded by a superfluid helium dewar is very similar to the layout of IRAS, as is the truncated sunshade. The scientific instruments are located radially around the optical axis, and the infrared beam can be directed into the

SIRTF TELESCOPE ASSEMBLY

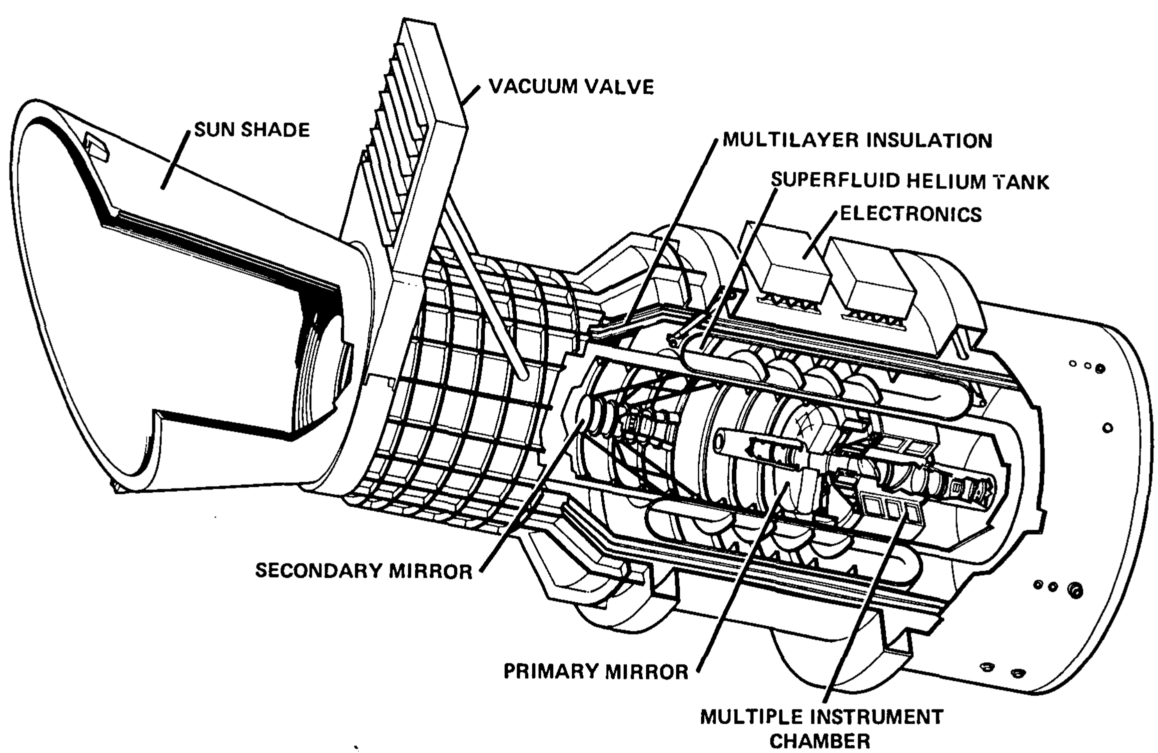

Figure 2.- A cutaway view of the long-life SIRTF telescope concept.

chosen instrument by a rotating dichroic. The optical radiation passes through to a fine guidance sensor within the dewar.

In table 1, the current performance requirements for SIRTF are compared with the actually achieved performance of IRAS. The table shows that in some areas the difference between SIRTF and IRAS is quantitative rather than qualitative. For instance, the collecting area is about three times larger, the optical quality is substantially improved, and the cryogen lifetime is about three times longer. The fundamental qualitative differences between SIRTF and IRAS are in two areas: (1) IRAS was a survey instrument with source dwell times typically <1 sec, whereas SIRTF is a pointed observatory, capable of studying individual sources for integration times up to ≈15 min per orbit; (2) IRAS's focal plane was designed to carry out an efficient all-sky survey, so the instrument had four broad spectral bands between 8 and 120 μm with fields of view large compared to the diffraction limit, together with a spectrometer providing low-resolution 7.3- to 23-μm spectra of the brighter sources. By contrast, SIRTF's large instrument chamber will

TABLE 1.- BASELINE SPECIFICATIONS FOR SIRTF WITH IRAS PERFORMANCE FOR COMPARISON

Parameter	SIRTF	IRAS
Primary mirror diameter, m	0.90	0.60
Effective collecting area, m^2	0.58	0.22
Wavelength coverage, μm	1.8 to 700	8 to 120
Diffraction-limited performance, μm	2	~15
Image diameter, arcsec	0.6	~6
Pointing stability, arcsec rms	0.1	2
Field of view, arc min	>7	60
Modulation	Secondary mirror articulation	Telescope scanning
Cryogen	Superfluid helium	Superfluid helium
Cryogen temperature, K	1.8	1.8
Optics temperature, K	<5	<5
Broadband sensitivity*		
10 μm	0.006 mJy	70 mJy
100 μm	0.1 mJy	300 mJy
Angular resolution at 60 μm, arcsec	18 (Diffraction-limited)	90 (Detector-width-limited)

*SIRTF sensitivity: 1 σ in 15 min
IRAS sensitivity: 1 σ survey scan

accommodate a number of focal plane instruments with wide-ranging capability. The instrument complement selected for definition for SIRTF (table 2) will provide at least the ability to measure spectra with resolving power between 50 and 1000 over the 2.5- to 200-μm region, to form images in either broad or narrow spectral bands at the diffraction limit of the telescope over the 1.8- to 200-μm region, and to make precise and sensitive flux measurements over the entire 1.8- to 700-μm region within which SIRTF will operate. The IRAS focal plane contained 76 discrete detectors, while SIRTF's instrumentation will include many thousands of detector elements, including both arrays and discrete detectors. Improvements in detector materials, fabrication techniques, and preamps since the definition of the IRAS focal plane will permit the SIRTF detectors, both discrete and arrays, to operate at the sensitivity levels set by the astrophysical background.

The instrumental capabilities of SIRTF are summarized and compared with those of IRAS in figure 3. The conclusion to be drawn from these considerations is

TABLE 2.- SIRTF INSTRUMENT COMPLEMENT
AND SCIENCE WORKING GROUP

Instrument	Principal investigator	Characteristics
Infrared array camera	G. Fazio, SAO	Wide-field and diffraction-limited imaging, 1.8-30 μm, using arrays with up to 128 x 128 pixels.
Infrared spectrometer	J. Houck, Cornell	Grating and prism spectrometers, 2.5-200 μm, using detector arrays. Resolving power from 50 to >1000.
Multiband imaging photometer	G. Rieke, Arizona	Background-limited imaging and photometry, 3-200 μm, with pixels sized to permit super-resolution. Broadband photometry 200-700 μm.

Other Science Working Group members, in addition to principal investigators:

M. Werner, NASA Ames, Project Scientist and SWG Chairman
F. Witteborn, NASA Ames, Deputy Project Scientist
F. Low, Arizona, Facility Scientist
M. Jura, UCLA, Interdisciplinary Scientist
E. Wright, UCLA, Interdisciplinary Scientist
N. Boggess, NASA Headquarters, Program Scientist

In addition, R. Brown, NASA Marshall Space Flight Center, is acting as a consultant to the SWG for the planetary sciences.

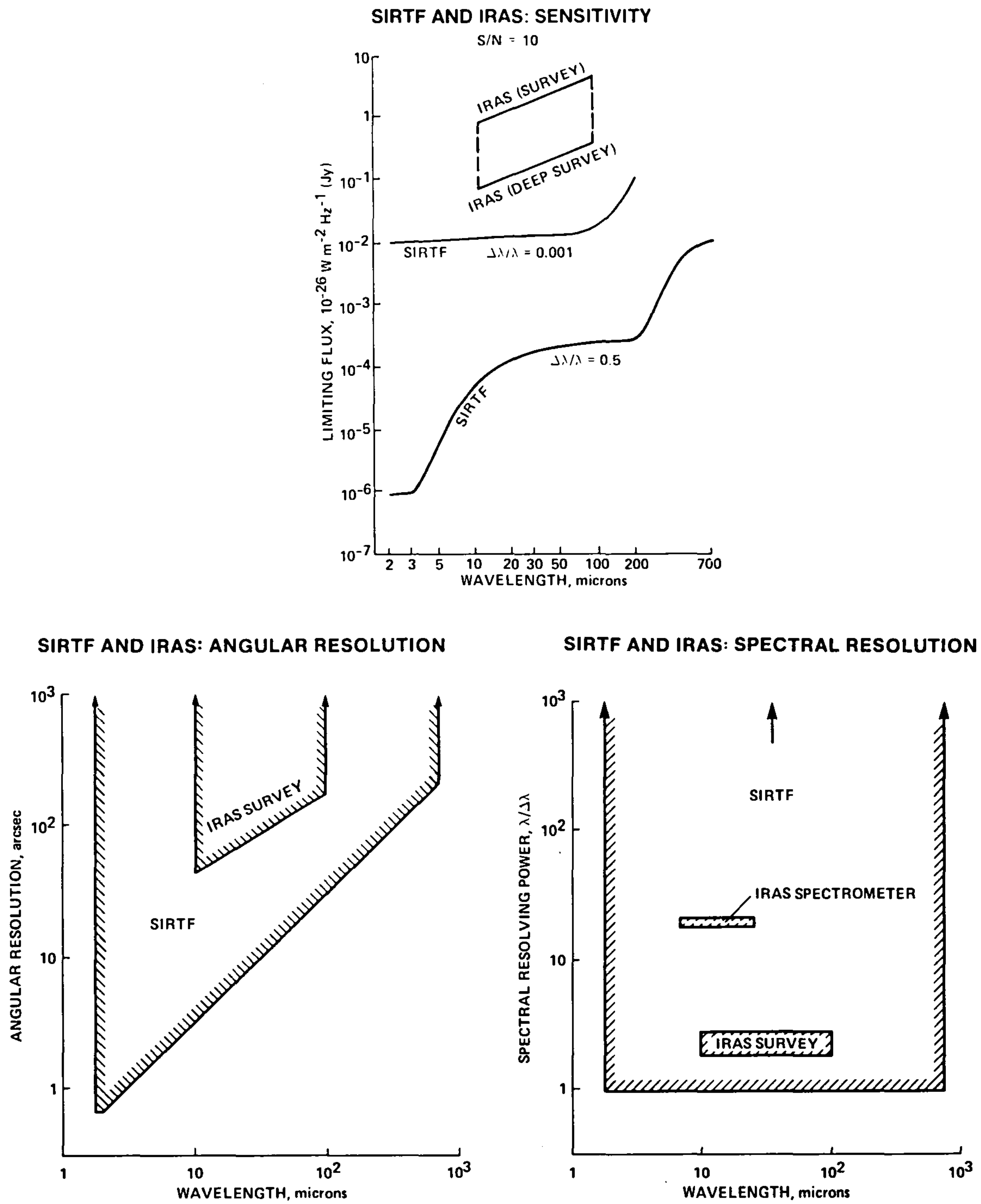

Figure 3.- The potential capabilities of SIRTF instruments in terms of sensitivity, spatial resolution, and spectral resolution are compared with the achieved performance of IRAS. The SIRTF sensitivity is shown in the top panel for both broadband ($\Delta\lambda/\lambda = 0.5$; background-limited) and high resolution ($\Delta\lambda/\lambda = 0.001$; based on proposed instrumental parameters) modes. An integration time of 15 minutes is assumed for SIRTF. The initial instrument complement currently under definition for SIRTF does not include spectroscopic capability longward of 200 μm.

that scientifically SIRTF is an enormous step forward--not only a step beyond IRAS, but beyond all our current capabilities. It combines the great power of a cryogenically cooled telescope outside the Earth's atmosphere with the spectral and imaging capability of state-of-the-art infrared instrumentation.

THE PROSPECTS FOR SIRTF SCIENCE

The scientific scope of SIRTF's capabilities may be summarized as follows:

Photometry

Natural-background-limited, by either photon or confusion noise, from <5 μm to close to 700 μm. SIRTF would thus be >1000 times more sensitive than either IRAS or any other current or near-term facilities. It is difficult to get a feeling for the significance of such a gain in sensitivity. As one example, SIRTF would be able to measure the energy distributions of all quasi-stellar objects (QSOs) brighter than 23rd visual magnitude if they have energy distributions like that of 3C273. Fainter QSOs appear to be redder, so in fact SIRTF would be even more powerful than this. By contrast, even after IRAS only a handful of quasars have been measured at 10 μm and beyond. A second way to look at the SIRTF sensitivity is that SIRTF will be able to observe stars with a 100-μm magnitude of about +9. Prior to IRAS, the only stellar photosphere detected beyond 20 μm was that of the sun. SIRTF will be able to study both the chromosphere-photosphere transition region in normal stars to beyond the limit of the Bright Star Catalog, and the circumstellar environment of extremely large numbers of abnormal stars exhibiting accretion and mass-loss processes.

Imagery

SIRTF will be capable of diffraction-limited imagery using arrays of substantial size in the 1.8 to 30-μm range, and smaller arrays for longer wavelengths, with sensitivity similar to that for photometry. The diffraction limit of an 0.85-m SIRTF is about 3 arcsec at 10 μm and 30 arcsec at 100 μm. This capability will be crucial for deep surveys, and for the study of extended objects, such as star formation regions in our galaxy, nearby galaxies, globular clusters, etc. Under some conditions, signal-to-noise ratio can be traded off for spatial information beyond the nominal diffraction limits, so that it should be possible to measure separations or sizes of bright (by SIRTF standards) sources down to 1 arcsec at 10 μm.

Spectroscopy

The infrared region contains many spectral features that make it extremely valuable for investigating a wide variety of environments and types of celestial objects. These include diffuse features associated with interstellar grains, such as those due to silicates at 9.6 and 20 μm and to H_2O ice at 3.1 μm. These features can be very strong even at low spectral resolution and thus should be an excellent method for measuring the redshifts of very red distant galaxies. The 1.8- to 500-μm region also contains all of the fundamental molecular vibrational transitions, as well as the fundamental rotational transitions in light molecules such as H_2, HD, and H_2O. The study of rotational transitions of heavier molecules in the microwave region has been vital to our understanding of the chemistry and dynamics in molecular clouds, but the infrared features will be particularly well suited for probing the higher temperature, higher excitation, more violent world associated with a star-forming region. The H_2 rotational transitions are very important, since most of the mass of molecular clouds is in this form, while the H_2O transitions are expected to dominate the cooling of the gas in a variety of environments. Finally, the many fine-structure forbidden transitions of heavy elements, both atoms and ions, which lie in the infrared are often strongly excited in HII regions and in the interstellar medium. The range of ionization states accessible to infrared observations, and the insensitivity of the line flux to electron temperature, will make SIRTF a powerful tool for the study of heavy-element abundances and abundance gradients in our galaxy and in external galaxies. The OI and CII fine structure lines at 63 and 158 μm are produced very efficiently in the diffuse interstellar medium and may be strong enough to be observed in gas-rich galaxies as distant as $z \approx 0.3$. SIRTF will also be capable of observing the faintest IRAS sources at a resolving power, R, of 1000 and most known QSOs at $R > 100$ throughout the 5- to 100-μm range.

Given these general capabilities, we can highlight the following four areas of scientific interest as ones which SIRTF will address particularly effectively:

IRAS Followup

By the time SIRTF is launched, there will have been an 8- to 10-year assessment of the IRAS catalog using our whole arsenal of observing and analysis techniques. This will yield three classes of results:

1. Improved understanding of the nature of the IRAS sources and of the physical processes occurring in them.

2. A long list of well-defined issues which require specific infrared observations for their resolution. For many of the fainter IRAS sources, SIRTF will be the only facility capable of these observations.

3. Sources which remain unclassified. These may include the most interesting findings of IRAS. Examples might be found among the cool discrete sources of high galactic latitude seen only at 60 and 100 μm. Many of these have been identified

with galaxies, some with infrared-to-optical luminosity ratios of 250 or more (for our galaxy the ratio is about one) and redshifts as high as $z \approx 0.2$. The total luminosity of these galaxies can exceed $10^{12}L_{\odot}$, comparable to the luminosity of QSOs. The fainter IRAS objects of this type may be among the most distant and luminous galaxies identified. SIRTF will be the only facility capable of detailed spectral study of these sources in the infrared, which will be required for their identification, for an understanding of their enormous luminosities, and even, in extreme cases, for distance determinations based on redshifted infrared spectral features.

Deep Survey

A second area of study would be a very deep survey, covering a few square degrees of sky at each of several wavelengths, which would require several hundred hours to complete. Such a survey would reach a flux level about 5000 times fainter than IRAS, and sample a volume roughly 30 times that sampled by the entire IRAS all-sky survey for objects of fixed luminosity. In addition, such a survey would cross critical sensitivity thresholds for the detection of astrophysically significant objects, both nearby and very distant. Examples include:

1. Brown dwarfs, sub-stellar objects which glow dimly through the release of gravitational energy. The SIRTF survey could identify up to 50 such objects, and their characteristics and space densities would test theories of their structure and formation and evaluate their contribution to the local missing mass.

2. An unbiased infrared sample of quasi-stellar objects. This set would allow a test of the reality of the cutoff in the density of QSOs at $z \approx 3$ to 4 and the possible role of extinction due to dust in producing this cutoff.

3. Primeval galaxies. If star formation occurs during the initial collapse of a primordial galaxy producing a luminosity $\approx 10^{12}L_{\odot}$, the SIRTF deep survey should detect large numbers of such primeval galaxies if the time of formation corresponds to a redshift $z < 15$.

Statistically Significant Samples

One of SIRTF's great advantages is its ability to carry out detailed spectroscopic and imaging studies of sufficient numbers of objects that the effects of individual idiosyncrasies can be averaged out, revealing the underlying physical processes. Samples of types of problems in this area are:

1. The origin of the difference between radio-loud and radio-quiet QSOs, which show similar energy distributions out to 100 μm, but differ dramatically at 1 mm.

2. The origin of the wide range of infrared luminosities of active galactic nuclei. At least two processes are thought to be involved in these nuclei, a "starburst" process in which the infrared luminosity is due to a large number of young, massive stars in the central 100- to 1000-pc of the galaxy, and a "nuclear

engine"--such as an accreting black hole--at least partially obscured by dust. Coordinated spectroscopic, photometric, and imaging observation of many objects over a wide range of wavelengths are required to understand the variety of processes and their interactions.

3. Star formation. Star formation is a very complex and intriguing process, and the IRAS results on star formation regions show complex structure on all spatial scales and a wide range of temperatures. SIRTF will be able very efficiently to obtain information critical to our understanding of the processes occurring in these regions. Examples include a detailed census of nearby star formation regions, leading to a determination of protostellar luminosity functions extending to low luminosity in a number of regions with varying properties. Recent work has shown that mass-loss phenomena--often manifested through energetic shocks--are of importance in the latter stages of star formation. These phenomena can be studied in a wide variety of environments in our own galaxy and in nearby galaxies.

Solar System Studies

Closer to home, SIRTF will be able to study the properties of a variety of solar system bodies--the surface composition of asteroids and planetary satellites in the outer solar system; studies of comets far from the Sun, including the development and composition of cometary comae; and the composition of the zodiacal dust cloud and the dust bands found by IRAS inclined to the ecliptic plane. The IRAS discovery of large, cool dust shells around Vega and Formalhaut opens up a new approach for solar system studies. The possibility that this material may represent a remnant of a phase of planetary system formation makes the study of the clouds found by IRAS and the search for further such objects very important and very exciting. Using SIRTF, much fainter shells can be detected, and detailed spectra can be obtained for composition and temperature studies and for searches for fluorescence phenomena associated with volatile molecules. High-spatial-resolution observations may be capable of addressing the question of the distribution of the material by distinguishing between rings, disks, and shells. SIRTF will help us to understand the evolutionary state of these clouds, the frequency of their occurrence, and the relation of this phenomenon to planetary formation.

SIRTF in Context

Most astrophysical problems require study over a broad range of wavelengths. Figure 4 shows how the SIRTF performance compares with that of other advanced facilities for space astronomy which will be operating in the 1990s and which are also components of the Golden Age of Astronomy. Like these other facilities, SIRTF will be a true observatory available to the entire scientific community. One can see how SIRTF nicely fills in most of the gap between the Space Telescope and the Very Large Array. Studies of energetic sources like QSOs, galactic jets, and BL Lac objects over extremely wide ranges of photon energy can be carried out with this combination of facilities. Coordinated observations have been and will be very important in understanding the nature and processes active in such sources. SIRTF will make it

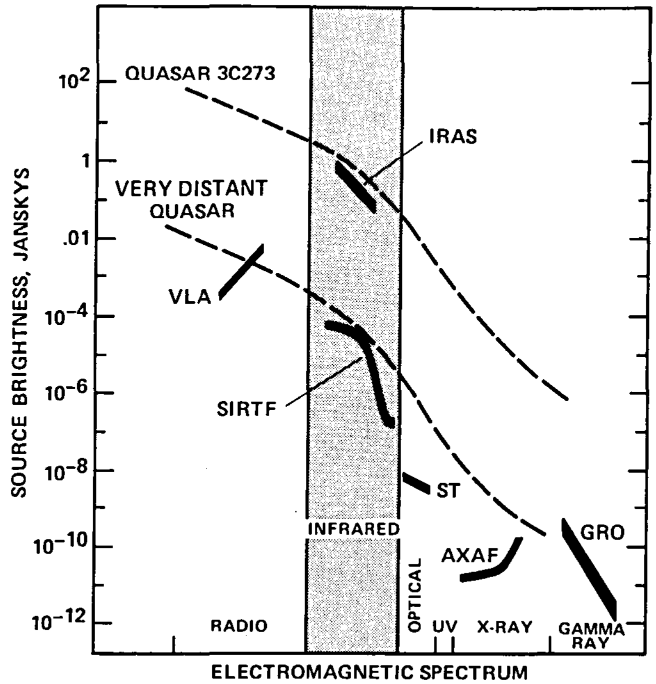

Figure 4.- The capabilities of SIRTF are compared with those of the other advanced facilities to be operating in the 1990s, and with the energy distribution of a distant quasar.

possible to include measurements over more than two decades in the infrared and thus assures us the capability to make measurements of faint objects across the entire electromagnetic spectrum.

TELESCOPE TECHNOLOGY

We have reviewed briefly the kinds of scientific investigations that SIRTF could undertake. It is clear that SIRTF can address many of the most interesting and important problems of astrophysics today. Now we will review the technical and then the programmatic status of SIRTF. The first of the Phase A studies for SIRTF started in 1974. These studies have been carried out by representatives of universities, industry, and NASA centers under the direction of the Ames Research Center (ARC) and with the help of several scientific advisory groups. Recently ARC finished the Phase A system concept description for a long-duration SIRTF. Since 1974 the total funding associated with these studies has amounted to about $15M. The studies have been directed toward developing a concept for the SIRTF facility and addressing areas of technological weakness. They have been largely completed, with work continuing in just a few areas. In addition, as mentioned previously, the technical success of IRAS has proven many of the technologies critical to SIRTF.

The important technical features of the current SIRTF concept include:

Cryogenics

The intent here is to build on the IRAS experience and other forthcoming experience with superfluid helium in space: the infrared telescope and superfluid helium experiment to be carried by the Shuttle in the Spacelab 2 flight in March 1985, and the Cosmic Background Explorer (COBE) dewar, currently under construction, which is somewhat larger than the IRAS dewar. SIRTF will take advantage of the Shuttle lift capacity and utilize a much larger dewar, perhaps eight times the size of the IRAS dewar. Because the instrument power dissipation and aperture loading are higher for SIRTF than for IRAS, it is expected that the larger cryogen capacity will result in about a lifetime three times longer for SIRTF--in excess of 2 years. Studies are now under way to look into the possibility of cryogen transfer in space so that the lifetime of SIRTF can be extended by several times, perhaps to a decade.

Optics

The IRAS optical system was made from beryllium and achieved diffraction-limited performance at around 15 μm. Because of the more stringent requirements for SIRTF, other materials have been investigated, and tests have been performed on a 50-cm-diameter fused quartz mirror. Cooling this mirror to 10 K introduced only marginally detectable distortion — consistent with diffraction-limited performance at 2 μm. The figure was maintained in cold tests carried out with the mirror mounted in a prototype mirror mount which provided mechanical rigidity while compensating for the differential contraction between the mirror and its support structure. Further cryogenic tests of mirrors and mirror mounts, including mirrors fabricated from a new ultrahomogeneous form of beryllium, are ongoing.

Pointing and Guiding

Coarse pointing and guiding will be accomplished using reaction wheels or control moment gyros in the spacecraft, with fine guidance accomplished via an optical charge-coupled device (CCD) in the telescope focal plane and an articulated secondary mirror to correct the pointing. Small telescope tests of CCD systems have been done, and warm tests of a sample articulated secondary mirror have been carried out, with further tests, including cold tests, planned.

Outside of these areas and the instruments, which will be discussed next, SIRTF has much in common with other NASA space facilities such as AXAF and GRO. SIRTF is between GRO and AXAF in weight, power requirements, and spacecraft pointing requirements. They have similar command and data storage requirements, and the SIRTF communication needs are within the standard capabilities of the Tracking Data and Relay Satellite System (TDRSS). Because SIRTF is very sensitive to residual atmospheric effects and requires orbital altitudes greater than 600 km, it would use the NASA Orbital Maneuvering Vehicle for insertion into final orbit and for retrieval

for cryogen replenishment. Both IRAS-type--polar, sun-synchronous, twilight terminator--and low-inclination orbits appear to be technically feasible for SIRTF; this trade will be the subject of further study during the coming months.

INSTRUMENT TECHNOLOGY

The initial instrument complement selected for definition studies for SIRTF is shown in table 2; the definition studies will be carried out over the next 2 years. There are a few general comments that can be made in terms of technological readiness, however. First, substantial experience already exists with cold infrared instruments for use with ground-based facilities, with the Kuiper Airborne Observatory, and with COBE, to name a few examples. Second, the crucial technologies and the critical advances of SIRTF over IRAS are in the areas of arrays and detectors. There have been major developments in this area in the last few years since the IRAS detector selection, including improvements in the materials and contacting techniques for photoconductive detectors and in preamplifier technology.

The noise equivalent power (NEP) (the power detected in 1 sec with unit signal to noise) of the IRAS detectors, which used transimpedance amplifiers, was about 10^{-16}W/$\sqrt{Hz}$. Recent work has been in the area of integrating preamps, where the effective NEP can be improved as a result of quieter components and longer integration times. This is essentially the same technique used in optical CCDs. For discrete detector preamps, read noises of about 10-20 electrons have been reported. With an integration time of 1 sec, this corresponds to an NEP of about 10^{-18}W/$\sqrt{Hz}$--roughly 100 times better than the IRAS detectors.

The infrared arrays available now are hybrid in character, with a detector section bonded to a multiplexing section. These arrays also use an integrating readout technique, with the integration occurring in the detector itself, as in a charge injection device (CID) or photodiode device, or in the multiplexer section. Recent measurements on what are called direct readout arrays have shown readout noise levels of about 100 electrons. Figure 5 shows what this means for SIRTF. It shows the NEP vs. wavelength for natural background limited performance for a diffraction limited field of view and a relatively narrow filter. Also shown is the NEP of an integrating detector with 1-sec integration time and 100-electron read noise. Because the NEP in this situation varies as $t^{-0.5}$, integration times of 10 to 100 sec are sufficient for background-limited performance with this read noise. This is again a major improvement compared to the IRAS detectors.

Self-scanned infrared arrays are also very useful on ground-based telescopes. In general, operation of these devices on a warm telescope is much more difficult than it will be on SIRTF. Because of the very high background of a warm telescope, very fast readouts are required, about 1-msec cycle time for the whole array at 10 μm, and the signal is extremely small compared to the background, perhaps one part in 10^5 or so. These considerations make the early results obtained with self-scanned arrays on ground-based telescopes all the more impressive. Figure 6 shows,

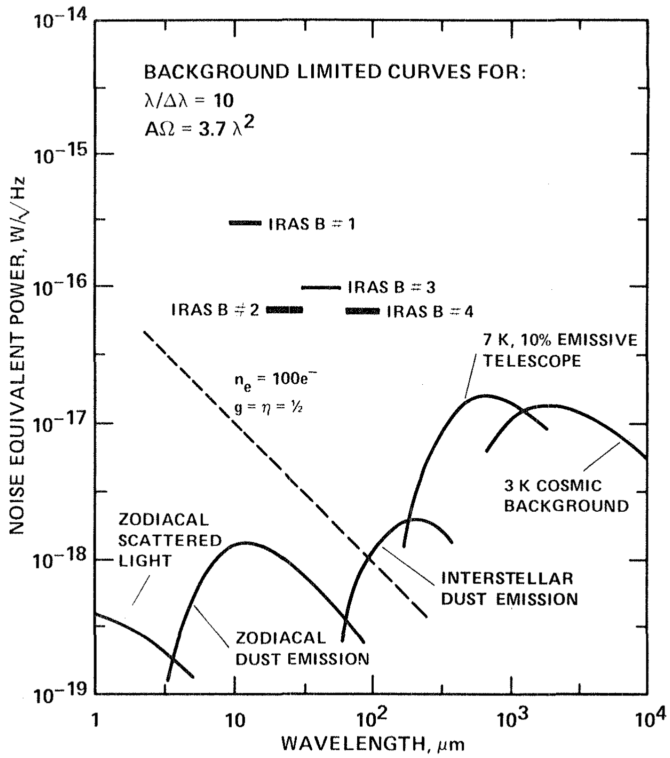

Figure 5.- The performance of a charge-integrating infrared detector with 100-electron read noise and quantum efficiency and photoconductive gain equal to 0.5, for 1 sec of integration, is compared with the natural and instrumental backgrounds for 10% resolution and diffraction-limited fields of view. The IRAS detector performance is shown for comparison.

for example, an early sample of a 10-μm-array picture of the galactic center region taken with a 16x16 Si:Bi CID array by workers at Ames, Goddard, the University of Arizona, and the Smithsonian Astrophysical Observatory. Clearly there is a lot of work to be done on infrared arrays in the next few years. Operation at low background, linearity, the effects of cosmic rays, and similar problems, have to be investigated in detail. Nevertheless, the prospects are extremely encouraging that infrared detector arrays that can take full advantage of the SIRTF environment will be available in the near future.

THE STATUS OF SIRTF

The SIRTF project has passed two critical milestones in the past year with the selection of the Science Working Group and the decision to proceed directly to the long-duration mission. SIRTF is shown in NASA's plans as a candidate for a new start in 1988, leading to a launch in 1993. Over the next several years, definition studies on both the instruments and the facility (Phase B studies) are to be carried

out, but it appears that there are no technological roadblocks in the path of a direct, long-duration SIRTF capable of exploiting the riches of the infrared spectral region.

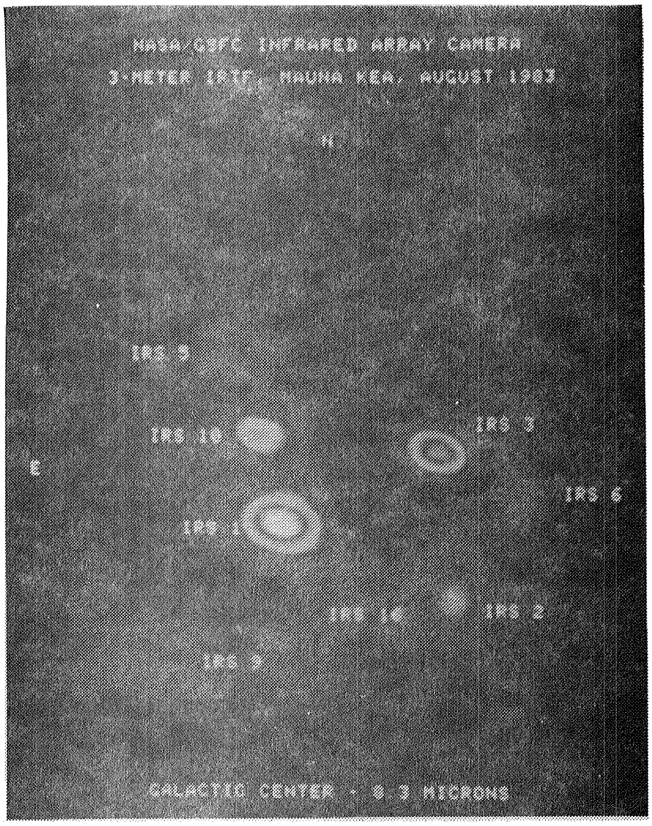

Figure 6.- 8.3-μm Imagery of the Galactic Center, obtained with a 16x16 Si:Bi array at the NASA Infrared Telescope Facility, Hawaii. This image has not been fully processed; the elliptical shape of some of the sources (e.g., IRS1, IRS3) is a result of row-to-row crosstalk.

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SIRTF — THE NEXT STEP

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16. Abstract

This paper describes the scientific and technical background and prospects for the Space Infrared Telescope Facility, SIRTF. SIRTF is a superfluid-helium-cooled, 0.85-meter infrared telescope to be placed in orbit in 1993. It will carry out photometry over the wavelength range 2 to 700 μm, and diffraction-limited imagery in either broad or narrow spectral bands over the range 1.8 to 200 μm, down to flux levels of 10^{-6} janskys at 2 μm, about 10^{-4} janskys in the range 15 to 200 μm and 10^{-2} janskys at 700 μm. These fluxes are up to 10^{4} times fainter than currently achievable levels. SIRTF will measure spectra in the range 2.5 to 200 μm with resolving power between 50 and 1000. The focal plane will contain about 20,000 detector elements, both discrete and in arrays, which will operate at sensitivity levels set by the astrophysical background. SIRTF will be a long-lived (≥ 10 yr) facility providing opportunities for general investigations by the entire scientific community.

SIRTF will be ideal for following up the all-sky survey carried out by the Infrared Astronomical Satellite (IRAS). SIRTF can do a deep survey to flux levels 5000 times fainter than IRAS and can obtain spectra of even the faintest IRAS sources. SIRTF will provide powerful capabilities for the study of astrophysical problems ranging from the formation of planetary systems and the nature of the Sun's nearest neighbors to the formation of galaxies in the early universe.

17. Key Words (Suggested by Author(s))

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